Catching up in science and technology: self-reliance or internationalization?

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Paper prepared for presentation in the session on "Nationalism and Internationalism of Science", research committee on the sociology of Science and Technology, International Sociological Association World Congress, Bielefeld, Germany, July 18-23, 1994.

1. Summary

This paper presents the main points of a recent policy paper for science and technology for Brazil, carried on by the Fundação Getúlio Vargas at the request of the Brazilian Ministry of Science and Technology and the World Bank[1]. In the 1960s and 1970s, Brazil carried on a very significant effort to build its scientific capabilities, but in the last decade this sector suffered intensely from lack of resources, institutional instability and lack of clarity about its role in the economy, society and education.

The policies of the sixties and seventies were geared to self-reliance. The purpose was to create competence in all fields of knowledge, and to develop competence in the production of weapons and heavy industry. This policy failed for internal and external reasons. Internally, it depended on a growing flux of public resources that became scarce in the 1980's. Externally, changes in the international economy created a buyer's market for consumer-oriented technologies; the intensification of international scientific communication turned science more international than ever; the end of the cold war rested legitimacy to large-scale, military-oriented projects; and the very nature of the scientific enterprise changed dramatically. Under the new conditions, self-reliance in science and technology in the traditional sense is untenable. A new concept of self-reliance is needed, in a context of growing internationalization.

[1] Schwartzman and others, 1995.

2. Science and Technology in Brazil: an overview

Brazil developed in the last 25 years the largest system of S&T in Latin America, one of the most significant among semi-industrialized countries. There are now about 15 thousand active scientists and researchers in the country[2] and about one thousand graduate programs in most fields of knowledge. Fellowships keep several thousand students in the best universities in the United States and Europe at any time. The number of research papers in international publications is the highest in the region.

Table 1. Brazil, expenditures in science and technology and Gross Domestic Product, 1980/1990, in US$ millions of 1991(*).

year	I- federal budget (2)	II-state budgets (2)	III- Government expenditures (I+II)	IV- Expenditures of the Productive sector	V - National Expenditures (III+IV)	VI - National expenditures as % of GDP	VI - Gross Domestic Product (GDP)(3)
1980	824.5	496.8	1,321.3	330.3	1,651.6	0.43	386,863.3
1981	1,519.6	672.4	2,192.0	548.0	2,740.0	0.74	370,279.2
1982	1,863.3	654.6	2,517.9	629.5	3,147.4	0.85	372,122.9
1983	1,475.4	462.6	1,938.0	484.5	2,422.5	0.67	359,727.6
1984	1,426.9	500.7	1,927.6	481.9	2,409.5	0.64	378,422.2
1985	1,953.9	501.9	2,455.8	613.9	3,069.7	0.75	408,151.6
1986	2,288.6	651.3	2,939.9	735.0	3,674.9	0.84	439,451.0
1987	2,556.1	466.9	3,023.0	755.7	3,778.7	0.83	455,424.2
1988	2,506.4	396.7	2,903.1	725.8	3,628.9	0.80	454,918.0
1989	2,147.1	512.5	2,659.6	664.9	3,324.5	0.71	469,663.5
1990	1,679.0	672.2	2,351.2	587.8	2,938.9	0.72	406,906.4

Source: Brisolla, forthcoming. Data from MCT-.CNPq/DAD/SUP/COOE.
Notes: (*) Deflated according to general price index of the Fundação Getúlio Vargas (IGP-DI/FGV) and converted to US dollars according to the average rate for 1991; (2) - actual expenditures; (3) - Corrected for inflation and converted to US dollars according to the average rate for 1991.

[2] This figure depends on what a "researcher" is. The Brazilian National Research Council (CNPq) listed 52,863 researchers in 1985, for about 3.5 million persons with higher education degrees. However, only 21.7% of researchers, or eleven thousand, had doctoral degrees. The number of university professors with doctoral degrees in 1991 was about 17 thousand, or 12% of the total. This figure is also consistent with the number of research proposals presented to the research councils in São Paulo (FAPESP) and Brasília (CNPq) each year (Brisolla, forthcoming; Martins and Queiroz, 1987; Schwartzman and Balbachevsky, 1992).

Most research activities in Brazil take place in universities. Brazil has about 1.5 million students enrolled in undergraduate programs, 30 thousand in masters and 10 thousand in doctoral programs. About one third of the undergraduate, and most of the graduate students are in public universities, which are free of charges. The remaining one million attend private institutions, which, with very few exceptions, do not have graduate education and research. The Federal government spent about 3.4 billion dollars on higher education in 1990[3] and the state of São Paulo an additional 871 million for its three universities (Goldemberg, forthcoming; Durham, 1993; Campanário and Serra, forthcoming). The gross per-capita costs for students in public universities are between five and eight thousand dollars a year, with most of the money going for salaries and the maintenance of hospitals[4]. For research, university professors have to apply to federal or state agencies, national and international private foundations, or to engage in research contracts with governments, public corporations and, to a lesser degree, private institutions.

3. The beginning: S&T development in a period of economic expansion

Some of Brazil's scientific institutions date from the late 19th century, and the National Research Council from the early 1950's. The larger part of the current S&T capability, however, was built during the 1968-1980 years, in a period of military rule (Schwartzman, 1991). Three factors contributed to this rapid expansion. The concern of some military and civilian authorities with the need to build up the country's S&T competence, as part of a broader project of national growth and self-sufficiency; the support this policy received from the scientific community, in spite of earlier (and often continuing) conflicts between scientists and academics and the government; and the economic expansion of the period, in which Brazil's economy grew at an annual rate of 7 to 10 percent. Another important element was the improvement of the government's ability to carry out policies in those years, through the establishment of small,

[3] These figures are only rough estimates, because of high inflation and unstable exchange rates.
[4] For different perspectives on student costs, see Paul and Wolynec, 1990, and Gaetani and Schwartzman, 1991. The estimation is that hospitals absorb about 10% of university's budgets (they have also other sources of income).

independent agencies outside the federal bureaucracy, and an expanding fiscal basis. The main initiatives in the period were the following:

The university reform of 1968, with the partial adoption of the American system of graduate education and the reorganization of the universities in terms of institutes, departments and the credit system;

- The placement of science and technology under the responsibility of the economic policy authorities, which allowed for a much higher influx of resources to S&T than ever before;
- The creation of a new Federal agency for S&T under the Ministry of Planning, the Financing Agency for Studies and Projects, FINEP, unencumbered by civil service routines and restrictions, and responsible for the administration of several hundred million dollars a year for science and technology support (Guimarães, R., forthcoming);
- The establishment of a few large-scale centres for R&D, such as the Coordination for Graduate Programs in Engineering of the Federal University in Rio de Janeiro (COPPE) and the University of Campinas, geared towards technological research and graduate education in engineering and sciences;
- The beginning of several programs of military research, such as the space program and the "parallel" nuclear program;
- The agreement with Germany for cooperation in nuclear energy, which was to create an autonomous capability in the construction of nuclear reactors based on locally reprocessed fuel;
- The establishment of a policy of market protection for the computer industry, telecommunications and microelectronics, linked to an emerging national private sector;
- The formulation, by the Federal Government, of successive National Plans for Scientific and Technological Development;

- The establishment of centres for technological research under the main state-owned corporations, which sought to keep up with the technological frontier, develop standards and transfer technology to their main suppliers;
- The strengthening and expansion of EMBRAPA, the Brazilian Corporation of Agricultural Research;
- The consolidation of peer review procedures in some of the main public agencies for science, technology and graduate education: CNPq, CAPES (the agency within the Ministry of Education providing fellowships for graduate studies) and the São Paulo Foundation for Research Support (FAPESP). The main federal agency for science and technology development in the seventies and eighties, however, FINEP, never introduced systematic peer review procedures although it works routinely with external consultants. Larger decisions of resource allocation in CNPq also remained usually outside peer review.

These policies of the last 25 years should be seen in terms of the changes in Brazilian society and economy in the previous decades. Between 1950 and 1980 Brazil turned from an agrarian into a highly urbanized society, but with high levels of social and economic inequality among regions and social groups. Employment in the primary sector went from 59.9% of the active population to 29.9% in those 30 years, while industrial employment went from 14.2% to 24.4%; the service sector, meanwhile, went from 25.9% to 45.7% (Faria, 1986). The industrial sector developed under the protection of tariff and non tariff barriers that shielded national, multinational and state-owned companies in the Brazilian territory from international competition. By 1970, the Brazilian industry supplied most of the demand for manufactured goods in the internal market, depending only on the import of sophisticated machine tools, chemicals, oil and electronics. A Strategic Program for Development, set by the Military government in 1968, sought to overcome these limitations. The country should build its own basic industry, develop its own sources of energy, and absorb the latest advances in science and technology. Starting with the Second National Development Plan, public corporations were created or expanded, subsidies were provided for the private sector, and barriers were raised against foreign competition, to protect the country's infant industries. Science and technology

were perceived as a central ingredient in this strategy, and received unprecedented support.

4. Crisis in the eighties and nineties

It is possible to point to several weaknesses in an otherwise successful policy of scientific growth. Links between S&T and the productive sector remained weak, lacking demands for advanced technology, in an economic environment characterized by protectionism and reliance on cheap labor and natural resources. The only significant exceptions occurred in the modern, export oriented sector of agriculture, which benefitted from research on the introduction of new varieties, the control of plagues, and the biological fixation of nitrogen, with very significant gains in productivity (Malavolta, 1986); in sectors associated with the large state corporations, such as telecommunications, energy, and the chemical industry; in the production of military equipment; and in the computer industry, with the attempt to link research with a protected industry of small computers for the internal market (Lucena, forthcoming; Tigre, forthcoming). For most other sectors, restrictions to the entrance of foreign technology and capital - as it happened with the computer sector in the eighties - were perceived as a hindrance and a burden. This difficulty was accentuated by the lack of understanding about the effective mechanisms and policies leading to technological innovation in the productive sector. The need to strengthen the country's basic technological infrastructure metrology, normalization, quality control and certification received only secondary attention, at least until the late seventies. In the universities, the new research and graduate programs remained often isolated from undergraduate education and teacher training. The quality of the scientific institutions created and expanded in the seventies was often not very high, and peer review procedures for quality control not always prevailed.

After 1980, the science and technology sector entered a period of great instability and uncertainty, characterized by institutional turmoil, bureaucratization, and budgetary uncertainty. The evolution of national expenditures for Science and Technology in the eighties, as illustrated on table 1, followed two parables. It grew in the first years of the decade, fell in 1983 and 1984, increased again with the short-lived economic expansion of the Cruzado Plan in 1985 and 1986, and fell sharply when inflation picked up again in

1988, reaching its lowest levels in 1991 and 1992 (Brisolla, forthcoming). In 1985, the National Fund for Scientific and Technological Development administrated by FINEP was just one fourth of its 1979 value.

This instability and uncertainty were related to economic stagnation, but also to an expanding arena of conflicting interests striving for public funds, and to an increase in political patronage (Botelho, 1990 and 1992). The S&T sector became one among many interest groups pressing for more resources, sometimes with partial success, but losing ground on the long run. The same pattern took place in most public universities, particularly in the federal system. The growing unionization of academic and administrative personnel allowed for significant gains in salaries, employment benefits, and participation in the universities' management, but stifled the institutions' ability to improve quality and make better use of their resources. The World Bank supported Program for Scientific and Technological Development (PADCT I, 1985, followed by PADCT II in 1990) was conceived in the early eighties, when the full dimension of the crisis was still to unfold. The program was supposed to improve the decision making capabilities of government, to strengthen R&D in biotechnology, chemistry and chemical engineering, earth sciences and mineral technology, instrumentation, physical environment and science education, and link it more directly with the productive system. In practice, instead of building upon a basis of existing resources, PADCT became often the only source of public support for the fields included in its priorities. Instead of improving the country's management and decision-making capabilities, it may have had the opposite effect, by creating an additional bureaucratic layer upon the existing institutions (Stemmer, forthcoming).

5. The achievements of the 1970s and the realities of the 1990s.

The scientific and technological competence acquired by Brazil in the last decades is an important asset for its continuous drive for social and economic modernization. There are, however, important questions and concerns about the adequacy of this system of S&T, as it was organized in the 1970s, to achieve what was expected from it. Part of the difficulty lies in the persistence of the assumptions that presided the S&T policies in the

sixties and seventies, when faced with the realities of the nineties; and part on the structures and vested interests created along these years.

a. The "endless frontier."

The basic assumptions that presided the development of S&T in Brazil during the sixties and seventies were not very different from those in the United States and other developed countries at the time. In both cases there was the notion of science as an "endless frontier," worth expanding for cultural reasons, for its beneficial effects in the quality of education, and for its promises about practical applications. All fields of knowledge equally deserving, and all good projects and initiatives should get public support. There were other resemblances: the importance given to military R&D; the notion that scientists should be funded by the state, free to control their institutions and distribute research resources according to their own criteria; and the assumption that social and economic benefits to society as a whole would necessarily derive from basic S&T in the universities and military research in government institutions (Branscomb, forthcoming).

b. Planning

There were also important differences. Brazilians believed more in comprehensive planning, and in planning for science and technology, than Americans did. There was, as there is still, a dire need for reliable information, and stable decision procedures for resource allocation and the establishment of long-term projects. The tradition was to try to fulfill these needs with comprehensive planning exercises, which could be turned into law and administered by the bureaucracy, thus making further decisions unnecessary. Three National Plans for Scientific and Technological Development were issued since the early seventies. Complex coordinating bodies (such as the Council of Science and Technology, CCT) were devised to try to link the research activities of different ministries. The Ministry of Science and Technology was created in 1985 as a response to demands from leading personalities in the scientific community, which expected it to fulfill this planning and coordinating role, making it more relevant to the country's economic and social needs. The notion that these links were to be achieved through

centralized planning contributed to the development of large bureaucracies for S&T administration.

c. Import substitution in science.

Another difference was that the development of S&T in Brazil was understood as part of a broader pattern of import substitution that was dominant in the economy, and led to barriers against foreign competition and the protection of infant industries. Although Brazil never attempted to develop a "national science," and valued its access to the scientific international community[5], the level and intensity of international interchanges was never as intense as that of other small scientific communities (Schott, forthcoming), and its research institutions and programs were seldom exposed directly to international standards of quality and evaluation. Considerations about regional inequalities and short-term needs, and political pressures for the creation of academic and research institutions throughout the country, led often to the weakening in the criteria for resource allocation by the government agencies.

d. Elitism in technology and education.

A final feature of the Brazilian S&T development effort has been the elitism of its technology and educational policy orientations, despite the political and socially progressive outlook of many of its promoters. Military technology was expected to be the harbinger of economic and technological modernization, leading to a disproportionate concern in government, diplomatic and academic circles, with the international constraints on the transfer of sensitive technologies. The two PADCT programs placed strong emphasis on the higher-end, frontier technologies, with a much smaller place given to science education, management and diffusion. Except in the field of health, there were no organized efforts to bring the benefits of scientific knowledge to the population as a whole, or to the basis of the productive system. In spite of the initial influence of the

[5] There were several proposals to create a typically "Brazilian" social science, based on the country's peculiar historical and cultural nature, from Gilberto Freyre to Alberto Guerreiro Ramos. Nothing similar, however, ever existed in the natural sciences, except in applied fields such as agriculture, natural resources and earth sciences, as should be expected.

American Land Grant colleges, Brazilian agricultural education and research remained restricted to a few institutions, and geared to the capital intensive, export sector of the economy (Azevedo, forthcoming). The recent effort to develop indigenous capability in computer science concentrated in the protection of the national hardware industry, rather than in the generalization of the use of the new technologies and competencies throughout society (Lucena, forthcoming; Tigre, forthcoming).

In education, Brazil tried to generalize the university research model before any serious attempt to deal with the problems of basic, secondary, technical and mass higher education. In consequence, the country has, simultaneously, some of the best universities and graduate programs, and one of the worst and unequal systems of basic education in the region. In practice, the university research model remained restricted to a few public universities in the São Paulo and in the federal system. Most other public institutions incorporated the institutional features and costs of modern universities (including full-time teaching, departmental organization, integrated campi, besides free tuition), without adequate mechanisms for quality assurance and the efficient use of public resources. About 65% of the students in higher education do not have access to public institutions, and attend the less prestigious, paying private institutions (Goldemberg, 1993; Schwartzman, Durham and Goldemberg, 1993).

Table 2: Brazil, Education figures: population of 5 years of age and above.				
	Brazil	Women	Rural	Northeast
Literacy (1990): Can read and write. self reported).				
5 years and more	76%	77%	58%	57%
10 to 14 years	86%	89%	70%	67%
60 years and more	56%	53%	32%	44%
Educational attainment (years completed)				
Total	100%	100%	100%	100%
one or more	82%	82%	65%	65%
two or more	77%	77%	57%	57%
three or more	68%	70%	46%	48%
four or more	59%	60%	34%	39%
five or more	41%	42%	17%	28%
six or more	33%	34%	11%	22%
seven or more	29%	30%	09%	19%
eight or more	25%	26%	07%	16%
nine or more	18%	19%	04%	12%
twelve or more	06%	06%	01%	03%
total (thousands)	113,629	58,373	28,011	31,614
Source: Fundação IBGE, Anuário Estatístico, 1992.				

Brazil had always been a highly stratified and unequal society. Even when the intention was there, governments had faced enormous difficulties in reaching the broader population with services like education, health and extension work. This situation should be reversed, but this does not mean that efforts to create good universities and competent research groups should be postponed until the problems of basic, technical and secondary education are solved, since these skills and competencies are essential for carrying on the needed transformations. It would be a mistake, however, to suppose that scientific,

technological and educational investments could not have had a broader impact on professional education and the dissemination of general and technical competence than they did. They can, but specific policies are needed for that.

6. New realities

a. Changes in the role of science and technology in the international scene.

- The international scene for science and technology has changed dramatically since Brazil begun its drive for S&T development in the sixties. The main features of the new context can be described as follows[6]:
- Science and technology are much closer to industry and markets than before. Industries depend, for the development of new management skills, processes and products, on specialized knowledge that cannot be generated anymore, as a matter of course, in their daily activities. The consequences have been an increase in R&D investments, the setting up of specialized laboratories and research departments, and the search for new links with universities. There is a renewed concern with the problems of intellectual property, which occurs in association with an expanded knowledge industry, carried on through licensing, technical assistance projects and international consulting.
- The pace of technical innovation and competition in industry has accelerated, requiring from firms a permanent capability to change its organization, absorb new technologies and processes and generate new products. This is leading to significant changes in the composition of the industrial labor force, with more emphasis given to highly skilled and motivated workers at all levels, and drastic reductions in administrative personnel and non qualified employees. Consequences of this acceleration of the pace of technical progress and intensification of market competition include the growing internationalization of industries and markets and the redefinition of production lines, with specialization in some segments of the production chain, or in some market niches. New associations and mergers, very often with companies from different countries, are

[6] For an overview, see Gibbons and others, forthcoming.

also prompted by the high financial costs of R&D and the shortened life-cycle of new products.

- Science is becoming more global. The speed, quality and low cost of international information flows bring researchers and research sites into immediate contact. The spreading of technological products and processes by international firms disseminates similar patterns of consumption, organization and work. It is much easier now to have access to the international scientific community than in the past, and the international mobility of talented researchers was also simplified. Simultaneously, there are increasing entrance requirements in terms of the standardization of scientific instruments, language and patterns of communication, leading to new inequalities and concentration of resources and skills.
- As the economic and military importance of scientific and technological knowledge increases, there is a growing tendency to limit its diffusion through legislation on intellectual property and governmental barriers to the diffusion of "sensitive" technologies. This tendency, however, is offset by the intense international competition of firms and governments to sell their technologies, and by the lack of well-defined boundaries between academic (and therefore free) and proprietary knowledge. The net result is that the bulk of modern technology is available for countries with the necessary pool of competence in engineering and basic sciences, except for a few military items that can still be controlled by the main powers.
- More recently, the end of the cold war is forcing the major powers into a difficult process of downsizing their military establishments, which is altering the traditional association between military R&D, industrial technology and basic academic research. Part of these resources will move to applied fields like health, the environment and energy, and new associations between government, research institutions and private corporations are likely to emerge. In these countries, scientific innovation in the new, civilian dominated context will be likely to be driven by markets and short-term social demands, rather than by government "requirements"; to be more incremental; more closely related to manufacturing

and service; and more cost-conscious than in the previous years (Branscomb, forthcoming).

b. Changes in the nature of the scientific enterprise

- The "simplest linear model" of scientific development and technological change is being abandoned. It assumed the existence of a pattern of *fundamental research* yielding discoveries and leading to the experimental findings of *applied science*, which allowed for acts of *invention*, which provided the basis of entrepreneurial *innovation*, creating new products and processes, which were later diffused by *imitation* and reverse engineering (David, 1992). The current view is much more complex. Scientific discoveries often take place in the context of application; there is no clear-cut distinction between basic and applied work; tacit knowledge and incremental improvements are more important than isolated scientific breakthroughs. One consequence of this changing perspective is that support for basic research has lost ground, when not linked to identifiable products and results. Other consequences can be listed:
- The development of new patterns of international scientific cooperation, with the establishment of large-scale international ventures such as the Human Genome Project and global research activities in the fields of meteorology, global warming, astrophysics, and regional cooperative projects. While traditional "big science" programs, such as the European Consortium for Nuclear Research (CERN), were characterized by large scientific installations, the recent ones tend to be organized in terms of extended and closely linked networks of scientists and research groups. For small scientific communities, the alternatives are either to participate in some aspects of these ventures, or to lag further behind.
- Because of its increasing costs, economic benefits and potential dangers, science and technology activities are more closely watched by society than in the past. Public controversies blur the frontiers between technical expertise and common knowledge, and a host of new activities and disciplines linked to scientific assessment have emerged, dealing with questions like technological forecasting, technology assessment and the evaluation of environmental effects of innovation.

The social sciences have acquired new relevance in this context, in the study of the economics of science and technology, the understanding of the social processes of education and knowledge production, the interpretation of public controversies, and in the analysis of public policy-making related to the field of S&T.

- The traditional organization of the scientific enterprise is under criticism. The division of academic departments and scientific institutions along disciplinary lines is being questioned on its ability to provide the proper training and conditions for interdisciplinary research. But there are no clear alternatives to the conventional organization of teaching and education along disciplinary lines, bringing a further source of tension between teaching and research. Government agencies for science support are being revised and transformed. The links between universities, government and industry are deeply changed by new patterns of technical education, cooperative research and financing, generating new opportunities and tensions. Traditional scientific careers are perceived as less rewarding, prestigious and secure than in the past, while new professional patterns emerge.

c. Changes in the nature and capabilities of the Brazilian state.

Brazil, which presented one of the world's highest rates of economic growth until the 1970's, did not adapt to the changing international environment of the eighties, and entered a prolonged period of economic stagnation *cum* inflation from which it is still to recover. Different explanations are given to this fact, going from the exhaustion of the import substitution model that characterized the country's economy since the 1930s, to the political and institutional inability of governments, since the eighties, to carry on long-term policies, in a context of international hardship and intense political competition for public subsidies. There is a clear notion, today, that the State has to reduce its size and its presence in the economy, while gaining competence to set and carry on long-term policies of economic growth, social welfare and environment protection. It is not clear, however, how this change should affect the S&T sector.

This situation of instability and lack of vision affected the S&T sector in two important ways. The most obvious was the reduction of resources for most existing programs, and the lack of perspectives for new projects and initiatives, even when international commitments, such as the loan contracts with the World Bank and the Inter American Development Bank, required well defined matching funds according to prescribed time tables. Probably more important were the problems of institutional and financial instability. The Ministry of Science and Technology changed name and status several times, budgets allocated to R&D institutions oscillated, and the actual delivery of these funds depended on constant, painful and daily negotiations with often unsympathetic economic authorities at the lower ranks in the bureaucracy. Not only resources were limited, but there was no consensus in government, public opinion, or international agencies, about the importance and role of scientific research, or about matters like basic vs. applied, civilian vs. military, academic vs. industrial research. This instability has been a matter of great concern, given the long time it takes for scientific institutions to mature, compared with the speed in which they decay in conditions of budgetary and institutional insecurity.

7. A new policy for a global world

In spite of the large science and technology gap between Brazil and the leading industrial nations, there might be an opportunity for convergence that should not be missed. Access to international information is cheap; circulation and mobility of scientists are intense; technologies for products and processes are offered in a highly competitive international market; multinational corporations spread their branches and research facilities throughout their world, depending on local conditions. The main requirements to seize this opportunity and share these knowledge resources are the country's social capabilities, which are essentially a matter of education and scientific competence (Abramovitz, 1986; Nelson and Wright, 1992). While science and technology are becoming more internationalized, the requirements to participate in their benefits remain local and national, and depend on purposeful efforts from local and national governments.

There is a definite need to move from the previous mode of scientific and technological development into a new one, more adequate to the current and future realities. Science and Technology are more important than ever for Brazil, if the country is to raise the standards of living of its population, consolidate a modern economy, and participate as a significant partner in an increasingly integrated and global world[7]. The economy must modernize, and adjust to an internationally competitive environment. Education should be expanded and improved at all levels. As the economy grows and new technologies are introduced, new challenges will emerge in the production and use of energy, environment control, public health, the management of large urban conglomerates, and changes will occur in the composition of the labor force. Strong indigenous competence is necessary to participate as an equal in international negotiations with important political and economic consequences for Brazil, in areas such as the protection of intellectual property and rights of access to information, norms of environment control and the establishment of technical standards in international communication networks. A traditional, laissez-faire approach to scientific and technological development will not produce the necessary competence on the scale and quality needed for these tasks, and will not make them as useful as they can be. There is little place left for protected technologies under artificial conditions, and large-scale, sophisticated and highly concentrated technological projects are not likely to spin off into education and industrial development as a whole. Attempts to bring the whole field of science and technology under the aegis of centralized planning and coordination run the risk of stimulating large and inefficient bureaucracies, and to stifle initiative and creativity.

The new policy should implement tasks that are apparently in contradiction: to stimulate the freedom, initiative and creativity of the researcher, while establishing strong links between their work and the requirements of the economy, the educational system and of society as a whole; and to make Brazilian science and technology truly international, while strengthening the country's educational and S&T capabilities. To achieve this, the individual researcher, and their research unit or laboratory, should be freed from bureaucratic and administrative constraints, and stimulated to look for the best

[7] The term "global" conveys the notion of an interdependent world civilization, with permeable boundaries and no clear hegemonic centers. There is a growing literature on the global nature of modern societies. See for instance Albrow and King, 1990; Robertson, 1992; Featherstone, 1992; Wallerstein, 1990.

opportunities and alternatives, in the country and abroad, for the use and improvement of his competence. This requires, in turn, a competitive environment based on public incentives and private opportunities that rewards achievement, increases the costs of complacency and underachievement, and gears a substantial part of the R&D resources towards a few important and strategic selected goals. To achieve these goals, the following recommendations are made:

a. To redirect the country's technology policies, in line with the new economic realities.

Technology policies are needed to make it possible for the country to enter a new pattern of industrial growth, centered on increasing levels of competitiveness. On the short run, the policies should be geared to the reorganization and technological modernization of the industrial sector. Then, permanent policies should exist to induce the more dynamic sectors of the productive system to enter a continuous process of innovation and incorporation of new technologies, to follow the rhythm of technical progress in the world economy. Both approaches require, as the main priority, the incorporation of existing technology to the productive process. Sectoral policies are needed for the reorganization and technological modernization of less efficient parts of the economy, and for the consolidation and expansion of the more dynamic industrial sectors. Support for research and development activities should be selective, and clearly associated with broader processes of innovation based on the transfer, diffusion and absorption of technological competence.

The issue of protectionism vs. market competitiveness in scientific and technological development should be approached in pragmatic, rather than in ideological terms. It is impossible, and it would be tragic, to shield the country from the technological revolution that is taking place in the world. A key element of this revolution is the role of multinational corporations and international trade in the development and diffusion of modern technologies, which makes the issues of technological development and international trade so intertwined. But a country should not renounce to its instruments of technological and industrial policy, including tax incentives, tariff protection, patent legislation, government procurement and long-term investments in technological projects,

in association with the private sector. The aim of these policies should be always to improve the country's scientific and technological competence, and reap the benefits of increased efficiency, productivity and trade. In this context, adequate legislation for patents and intellectual property should be established, with the understanding that they are necessary for the normalization of Brazil's relations with the industrialized countries, although, on itself, such legislation could neither guarantee nor jeopardize the technological advancement of Brazilian industry (Pereira, forthcoming).

b. To protect the existing pool of scientific competence.

Many of the best R&D institutions and groups are being dismantled by absolute lack of resources, and emergency measures are needed to deter this process. The government should guarantee a stable and predictable flux of resources to its main S&T agencies for their daily routines and "over the counter," peer reviewed research supporting activities. The problem is not just of limited resources, but above all of lack of institutional stability and commitment with the sector, since the resources needed is not very high. Special programs like the PADCT could be used for this purpose. Not only the agencies need to have their resources, but the most qualified research institutions and groups should be preserved in their ability to keep their best researchers and their work.

c. To develop a three-pronged policy for S&T development, with clearly distinguished support mechanisms for basic science, applied work and extension and education.

Basic Science. The fact that basic science, applied R&D and high level technical education are very often indistinguishable, and take place simultaneously in the same institutions, does not mean that they should not be treated separately in terms of their supporting mechanisms, working from different perspectives and with different approaches.

Basic or academic science, broadly understood as research work that does not respond to short-term practical demands, remains necessary not only for its eventual role as the source of privileged discoveries for applied work, but because of its nature as an

indispensable public good. Scientists should be trained on a broad fundamental basis, so that they will not become obsolete in a short time. This purpose is not in contradiction with applied work, but should not be jeopardized by too much emphasis on efforts to help solve short-term operational problems of the productive sector. In spite of the growing presence of proprietary knowledge in modern societies, academic science is also expanding, and the resources it can expect from the private sector are not very high. The information basic science generates is free for the private sector (although it is paid by society as a whole), and is the main source for the acquisition and spreading of the basis of tacit knowledge that permeates the whole field of science, technology and education. For a leading country, heavy investments in basic science can be thought of as problematical, since their results can be appropriated by other countries and regions for very little cost. For the same reason, investments in basic science in small scientific communities can be extremely productive, since they allow tapping the international pool of knowledge, competence and information. This is the rationale for projects such as the National Laboratory of Synchrotron Light, now under construction by CNPq (Resende, forthcoming).

Besides its eventual impact on the productive sector, basic science can play a fundamental role in enhancing the quality of higher education for engineers and for society as a whole. This role, however, does not take place as a matter of course. Universities have to develop explicit links between their graduate and undergraduate programs; intellectual and financial investments have to be made for the development of materials for science teaching, from handbooks to educational software and experimental kits. When these links and investments exist, basic science becomes more legitimate, and more likely to be supported by society.

Applied science. The central feature of applied science is that it has a user, and the knowledge generated in the R&D process tends to be proprietary. The main clients for applied science in Brazil have been the military, the large state-owned corporations and a small section of the private sector, including the export-driven agricultural firms. There is a clear trend away from these kinds of R&D activities, however. In the current international context, there are limits on what smaller and poorer countries can do in

terms of military prowess. In contrast, there is a strong premium on the spreading of education, technical competence and competitiveness through society. Most public corporations are either being privatized or forced to rely on market mechanisms to survive. In both cases, publicly subsidized applied R&D will tend to diminish. The Brazilian experience of subsidized R&D to the private sector is not very good. If loans are granted below the market interest rates, there may be many takers, but the outcomes are often poor. There is a room, however, for special procedures to finance long-term and joint R&D projects that would not otherwise find support through commercial banks. General policies and support mechanisms for applied R&D are difficult to devise, since they refer to an extremely variegated range of activities, and require different combinations of economic, scientific and strategic considerations.

Education. The main challenge for Brazilian science and technology in the coming years is to spread competence for innovation horizontally, to the productive system as a whole, and to increase the educational level of the population. While this is not done, the S&T establishment is bound to relate only to a small part of the country and its economy, with limited resources and relevance. Brazil has maintained a wide gulf between education for the academic professions, including engineering, and middle-level professional training, the first provided by universities, the second by federal and state technical schools (and also by industry and commerce through their own institutions, SENAI and SENAC). The knowledge-intensive basis of modern industry and services requires the development of general skills for the technician, and proximity with industry for the institutions trying to provide technical education through formal course programs (Castro and Oliveira, forthcoming). Brazil has lagged behind the worldwide trend of developing post-secondary, short-term course programs as alternatives to conventional university education. The expansion of post secondary, technical education, developed with close links to industry, should become a central task for public universities and state governments. Although more difficult at the beginning, this new emphasis could prove more useful than the sheer expansion of evening course programs that became mandatory for public universities in the recent past; and more realistic, in budgetary terms, than the proposed multiplication of federal technical schools operated by the Ministry of

Education.

d. Institutional reform.

For these policies to be carried on, governmental agencies for S&T policy should become smaller, more flexible and more efficient. These are some of the current suggestions for reform:

- The Ministry of Science and Technology should restrict its role to matters of policy, financing, assessment and evaluation, without carrying on R&D activities under its direct administration. Although a science adviser or an equivalent cabinet-level position for science and technology is clearly necessary, the very existence of a formal ministry of science and technology, with all its overhead costs and exposure to political patronage, should be reexamined.
- The existing system of federal institutions for scientific and technological support should be evaluated in terms of its ability to perform the functions needed by the sector: support for basic research, support for applied projects, large and small research grants, fellowship and training programs, scientific information, norms and standards, and others.
- Financing agencies should be organized as independent, state owned corporations, and free of formalistic and bureaucratic constraints. They should be placed under strict limitations regarding the percentage of their resources they can spend on administration, and should be supervised by high-level councils with the participation of scientists, educators, entrepreneurs and government officers. They should rely on external advise for their decisions, and their bureaucracy should be limited to the minimum.
- Research institutions and public universities should not be run as sections of the civil service. They need to have the flexibility to set priorities, seek resources from different public and private agencies, and establish their own personnel policies. While this is not changed, there is always the alternative of developing hybrid institutions with flexible mechanisms coexisting with more rigid

procedures (the Brazilian academic community has some experience in this). Universities should develop appropriate settings for interdisciplinary work in new fields such as biotechnology and artificial intelligence (Carvalho, forthcoming; Silva, forthcoming).

- No research institution receiving public support, and no government program providing grants, fellowships, institutional support or other resources to the S&T sector, should be exempt from clear and well-defined procedures of peer evaluation, combined, when necessary, with other types of economic and strategic assessments. Peer review procedures should be strengthened by the federal government, made free from pressures of regional, professional and institutional interest groups, and acquire a strong international dimension.

Conclusion

Globalization requires a profound rethinking of the old dilemma between scientific self-sufficiency and internationalization. Self reliance today does not depend so much on the control of specific technologies or on nationally owned industries, but above all on the existence of a highly educated population, and of scientific and technological communities with enough competence, flexibility and incentives to look for knowledge and information wherever they can be found. The experience of small, high-level scientific communities in countries like Canada, Israel, the Netherlands and Scandinavia, shows that this may be a spurious question. They built their competence through a purposeful effort to be present in the international scientific scene, by the extensive use of the English language, participation in joint research projects, evaluation of their research activities by scientists from other countries, and a constant international flux of students, researchers and information; they are not less developed, and their science less relevant for their societies, for that reason.

The plurality and complexity of modern science and technology require the research institutions in universities, government and even the private sector to engage in a plurality of activities, from basic to applied science, from graduate education to extension

work and teacher training. They should be also stimulated to diversify their sources of money, from government to private companies, nonprofit foundations and paying clients and students. Specialization will take place, is necessary, and should grow through a combination of external incentives and internal drive. Scientific research and development, to remain alive, should take place in a highly internationalized and competitive environment for resources, prestige and recognition; and the leading scientists should be also entrepreneurs of this knowledge enterprise.

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